# A NEW HORIZONTAL ELECTRON MICROSCOPE

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Plates XVIA and XVIB

**ABSTRACT.** A new horizontal electron microscope with several special features has been constructed. The technical details of its construction, power supplies and operation are given in this paper. The microscope can be operated at a maximum electron energy of 80,000 electron volts and is designed for an electron optical magnification of twenty thousand diameters.

## INTRODUCTION—HISTORICAL

An electron microscope with several distinctive features has been produced in the University College of Science, Calcutta. It is the aim of this paper to describe these features in detail. However, from the point of view of interest to the reader, a short historical account of the development of the electron microscope up to its present stage will be given, before the technical features of the new microscope are described.

The science of electron optics is of recent origin Its basis is the fundamental theoretical work on electron lenses by Busch who first showed in 1926, that axially symmetric electric and magnetic fields possess lens characteristics with respect to electron radiation. The practical development of magnetic lenses was carried out by Knoll and Ruska (1931, 1932) in the Technische Hochschule, Berlin. The first electron microscope employing magnetic lenses with pole pieces—the prototype of all modern instruments—was constructed by Ruska in 1934 A cold cathode gas discharge tube was used as the source of electrons, there was no provision for air-lock arrangement for introduction and removal of specimens and the final image formed on a fluorescent screen was photographed through a window by means of an external camera. Marton introduced several improvements in the design of an electron microscope developed by him in the University of Brussels, in 1935. He used a heated filament, air-lock specimen chamber and arrangement for direct recording of electron micrographs on photographic plates introduced into the vacuum. He was also the first to photograph biological specimens with an electron microscope.

Two years later in 1937, the first electron microscope in Britain was constructed by the Metropolitan Vickers Company for Martin, Whelpton and Parnum 137. At about the same time Burton in Canada organised a programme of research in electron microscopy in the University of Toronto. Two of his graduate students, Prebus and Hillier (1939) built the first electron microscope in America. By 1939 resolving powers better than 100 A° were obtained by Canadian and European workers. (Burton, Hillier and Prebus 1939).

At this stage when the great potentialities of the new microscope was well proved by these successful research instruments, developed primarily in the university laboratories, industry took up further development. The first commercial electron microscope was built at about this time by Siemen's company in Berlin (Borris and Ruska 1939, 1940). The lens coils and the filament of the microscope used current from storage batteries and the coils were water cooled. The high voltage unit consisting of the conventional transformer rectifier system was in a seperate assembly on account of its great bulk and for better shielding of the microscope from sixty cycle electro-magnetic radiation.

Von Ardenne in 1940 published a description of his universal electron microscope developed in the Kaiser Wilhelm Institute, Berlin. It was designed for bright field, dark field and sterio operation. The notable features of this instrument were the arrangement for tilting of the specimen for sterioscopic photography and perfect alignment and also the possibility of direct electronic magnification up to 50,000 diameters.

In 1939 Marton came to U. S. A. and joined the R. C. A laboratories. There he developed the first R. C. A. electron microscope called R. C. A. type A (Marton 1940, Marton, Banca and Bender 1940). A year later R. C. A. announced the development of the first commercial electron microscope in U. S. A, called R. C. A. type B (Zworykin, Hillier, and Vance 1941 *a*, Hillier and Vance 1941). The chief improvements on its predecessors were (a) combination in a single unit of both the microscope and its power supplies and (b) the use of high frequencies for generation of high voltage and heating of the filament. For stabilisation of the high voltage, feed-back principle was used.

In 1941 various attempts were made to increase the electron energies so as to make possible the examination of thicker specimens with the help of an electron microscope. Müller and Ruska (1941) adopted a Siemens microscope for operation at 220 ekv. Von Ardenne (1941) modified his electron microscope described earlier for operation at 200 ekv. Zworykin, Hillier and Vance (1941*b*) also reported the construction of a 300 ekv. microscope.

In these cases the microscope body was similar to those already described. Only the electron gun was built in two or three stages and the voltage distributed between them by means of a voltage divider across the high voltage supply for stable operation.

In 1942 Prebus built an electron microscope in the Ohio State University, Columbus, following the design already developed at Toronto. Microscopes

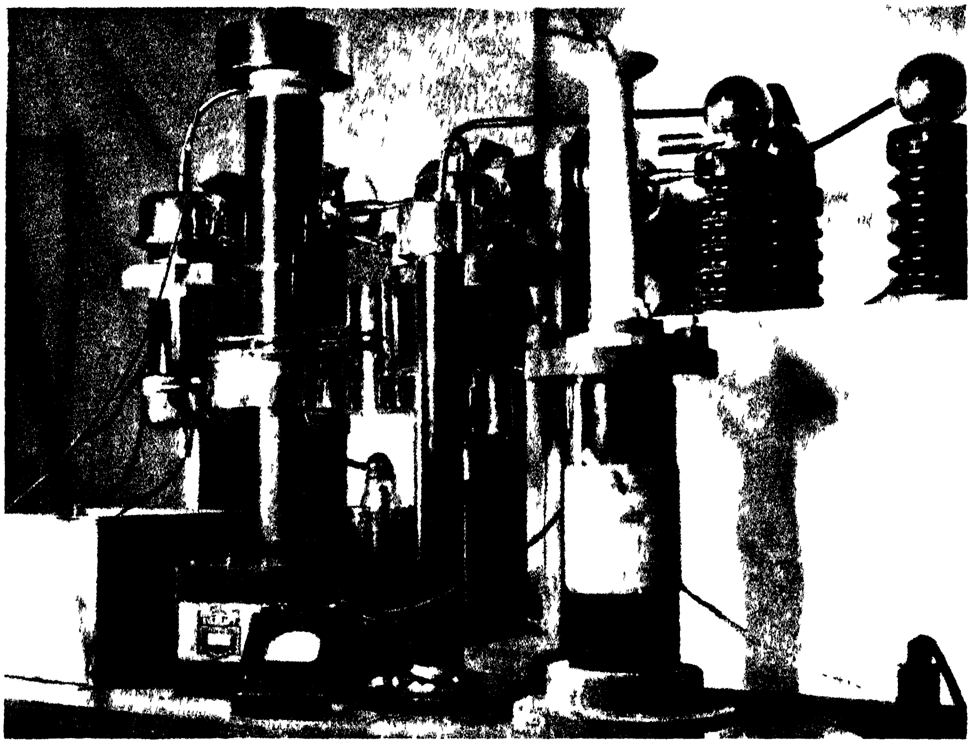

Fig 8

Photograph of High Frequency Voltage Unit based on this design were also installed at the Eastman Kodak Co. and in Columbia Carbon Co., in U.S.A. In the subsequent year R.C.A. announced the development of a small compact electron microscope called R.C.A. console model (Zworykin and Hillier 1943). In this unit the condenser lens was eliminated and the objective and the projector lenses contained in the same magnetic circuit. This extreme simplicity of design had been obtained at the cost of a fixed magnification of only 5000 diameters and an operating voltage of only 30 ekv. The resolution was reported to be better than 100 A°.

In 1945 Marton, now at the University of Stanford, produced an electron microscope employing five lenses and designed for three stage magnification which could be varied from 400—40,000 diameters. This microscope had an intermediate lens in between the usual objective and the projector lenses and was designed for operation at 100 ekv.

During war the research and development of electron microscopes was mostly restricted to U.S.A. However, some work was carried on with great difficulty in Holland, France and Great Britain. Poole developed in 1944 an electron microscope in the Institute of Electron Optics at Delft, Holland whose details have just been published (Poole 1947). This instrument operates at 150 ekv and is a four lens unit. With a distance of only 60 cms between the object and the final image the magnification produced can be varied continuously between 1000 and 80,000 diameters. This instrument has also an arrangement for using 35 mm. film. In 1947 the Metropolitan Vickers Co. in England anounced the production of the first commercial electron microscope in England EM3 Model of Metro Vick. (Haine 1947).

The instruments described so far are electromagnetic instruments using electromagnetic type of lenses. The development of electrostatic lenses and of electron microscopes using such lenses has proceeded almost side by side with that of the electromagnetic instruments. Shortly after Busch's original discovery, Davisson and Calbick (1932) in U. S. A. and Brüche and Johannson (1932*a*) in the A. E. G. laboratories in Berlin successfully developed electrostatic lenses. Brüche and Hagen (1939) and Mahl (1939) designed the first electrostatic microscope of high magnification in the A. E. G. laboratories in Berlin. Boersch (1942) built at the University of Vienna a versatile type of electrostatic electron microscope. This instrument could be easily adapted for taking the usual transmission pictures, electron shadow micrographs as well as diffraction patterns. In 1943 Bachman and Ramo, of the G. E. C. laboratory in U. S. A. developed a three stage electrostatic instrument. With a very simplified design they obtained a resolution 10 times that of the light microscope and an electronic magnification varying from 500-1000 diameters. In France, the Compagnie Generale de Telegraphie sans Fil (C.S.F.) has also produced an electrostatic instrument. Although the electrostatic instruments are simpler to construct, from the point of view of ultimate performance they have not yet appeared on the market as any serious rival of the electromagnetic instruments.

## DESCRIPTION OF THE NEW MICROSCOPE

An illustration of the new electron microscope is given in Plate XVIA, Fig. 1. Fig. 2 shows a section of the complete electron optical system. There are several

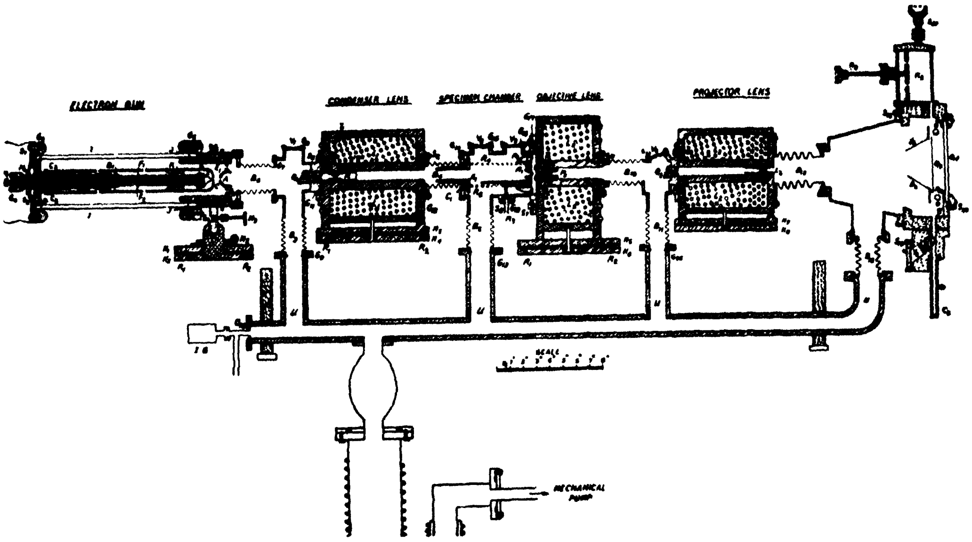

FIG. 2
Sectional Diagram of the New Microscope

features which distinguish this unit from all the instruments described earlier. This instrument is a completely horizontal unit with different elements mounted on two stainless steel rods held in position by brass sleevings which can slide over the steel rods. It is thus possible to dismantle any part of the microscope without disturbing the rest. The distance between any two elements can be varied, it is also possible to interpose an extra element between two of the existing ones if desired. The instrument is thus essentially a research unit, very flexible in design and highly suited for investigations on electron-optical problems. Due to horizontal positioning each microscope element is approachable from all sides and the image formed on the final fluorescent screen can be demonstrated to a number of people simultaneously. The instrument consists of the usual three lenses, the condenser, the objective and projector lenses and is designed for a maximum electronic magnification of twenty thousand diameters.

The electron gun, the condenser, the objective and the projector lenses are supported on separate carriages consisting of pairs of horizontal brass plates $H_1$ $H_2$, $H_3$ $H_4$, $H_5$ $H_6$, and $H_7$ $H_6$. Any of the pairs of brass plates can slide together in a horizontal plane perpendicular to the axis of the microscope on a pair of stainless steel guide rods $R_1$ $R_2$, fixed to the frame of the instrument. The upper plates $H_1$, $H_3$, $H_6$and $H_7$ supporting the microscope elements can also be raised or lowered with respect to the lower plates by a set of screws. These two motions at right angles to the optic axis can be given to any element of the microscope. By means of transmission gear arrangement the operator, sitting at the control table near the final fluorescent screen, can move any of the lenses or the gun for proper alignment. Each of the three lenses has four levelling screws by means of which the lens may be slightly inclined to the axis so as to allow for any asymmetry of the pole pieces. In addition to lateral motions, the gun can be slightly tilted about horizontal and vertical axes passing through the tip of the filament F, by means of the screws $M_3$ and $M_2$ respectively.

The different elements are connected with one another and with the vacuum manifold $U$ by sylphon bellows so that relative movement is possible maintaining the vacuum. The length of the microscope column from the filament tip to the objective is 59 cm. and the length from the objective to the fluorescent screen $Q_4$ is 79 cms. For evacuating the microscope column an oil diffussion pump and a Cenco Hypervac 20 are used. The mechanical pump is housed in a specially designed underground chamber a little distance away from the microscope in order to reduce noise and vibration. A thermocouple gauge measures the fore-vacuum while the high vacuum within the microscope is indicated by an ionization gauge.

### *A. Illuminating System*

The illuminating system consisting of the electron gun, the primary viewing screen $Q_1$ and the condenser lens $L_1$ is shown in the figure 3. The electron gun is a three electrode system consisting of the filament F, cathode shield $C$ and the anode $A$. The filament consists of a .005 inch diameter tungsten wire bent into hair pin shape. The filament current leads $F_1$, $F_2$ consist of a steel cylinder surrounding a steel rod; the two are kept insulated from each other by means of a pyrex tube. The filament is heated by means of a high-frequency (150 kc/s) current and may be maintained at a maximum negative potential of 80 ekv. with respect to the anode which is earthed together with the main body of the microscope. The cathode shield is a cylinder of stainless steel with an 1/8 inch diameter aperture, located just in front of the filament tip. The filament is kept fixed axially within the cathode shield by means of an alsimag cylinder $K$. For changing the filament, a part of the cathode shield may be unscrewed at $C_1$. The cathode shield is insulated from the filament and may be suitably biased when it serves as a control grid. The distance between the filament tip and the centre of the shield can be varied by means of the adjusting screw $M_1$ at the high potential end.

The anode $A$ is a copper hemisphere, drilled axially with an 1/8 inch hole to allow the beam to pass through. The distance between the anode and grid aperture is about 1 inch but may be adjusted by screwing at $C_2$. The anode is surrounded by a steel shield $E_1$ which cuts off X-radiation from the anode due to bombardment of high energy electrons. The high voltage insulator $I$ consists of one ft. long pyrexcylinder metallised at the end to which are soldered steel flanges $J$ on either end. The complete filament assembly is held in position by the centering aluminium disc $D$. The whole

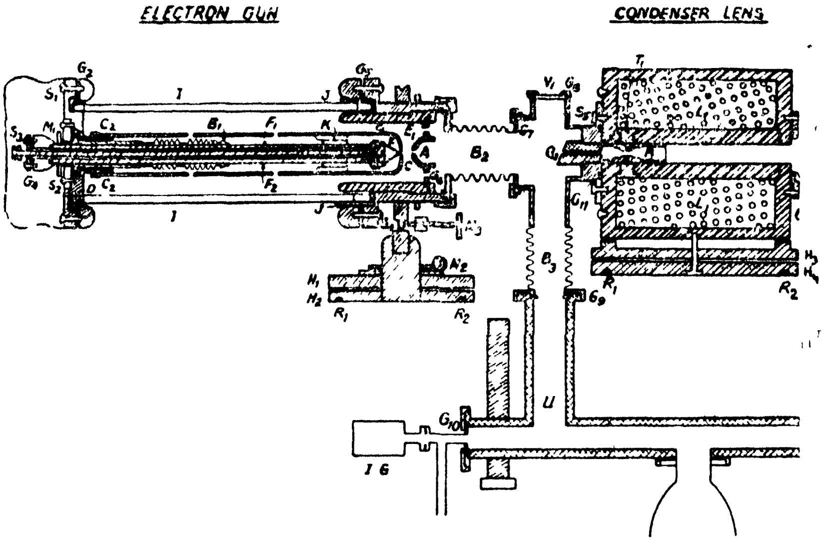


FIG. 3

Illuminating System of the New Microscope

$A$ anode, $B_1$-$B_3$ sylphon bellows, $C$ cathode shield, $I$ filament, $G_1$-$G_{11}$ vacuum gaskets, $H_1$-$H_4$ brass carriages for movement of the electron gun and condenser lens, $I$ metallised pyrex insulator, $J$ steel flanges soldered to the insulator, $K$ alsimag cylinder, $L_1$ condenser lens coil, $M_1$-$M_3$ adjusting screws for controlling the position of the electron gun, $P_1$ condenser pole piece, $Q_1$ primary viewing fluorescent screen, $R_1$, $R_2$ rods permitting horizontal motion of the gun and condenser lens, $S_1$-$S$, gasket tightening screws, $T_1$ brass spacer in condenser lens, $U$ vacuum manifold, $V_1$ viewing port

gun assembly is demountable and is made vacuum tight by means of the rubber gaskets $G_1-G_6$ and gasket tightening screws $S_1-S_1$. For a change of filament, the filament unit together with the cathode shield can be taken out by unscrewing $S_1$.

The electron beam after leaving the gun assembly falls on the primary fluorescent screen $Q_1$ which is a copper rod with an axially drilled hole. This allows the central portion of the beam to pass through and enter the condenser lens $L_1$. $V_1$ is a small port for viewing the crosssection of the illuminating beam at this position.

The condenser lens $L_1$ is also shown in Fig. 3. It consists of a coil housed in an iron cylinder of length $7\frac{1}{4}$ inches, external diameter $6\frac{1}{2}$ inches and internal diameter 5/8 inch. The magnetic circuit is completed through the iron except for a small gap bridged by non-magnetic brass piece $T_1$, through which the field extends into the vacuum. The field is further concentrated by the insertion of accurately machined pole pieces $P_1$ of special design, drilled with a central hole for the passage of electrons. The coil of the condenser lens is outside the vacuum system; only the inner hole of 5/8 inch diameter is connected to the vacuum system.

*B Specimen Chamber*

A vertical section of the specimen chamber through the optic axis is shown in Fig. 4. The object stage $N$ is held in position by means of four

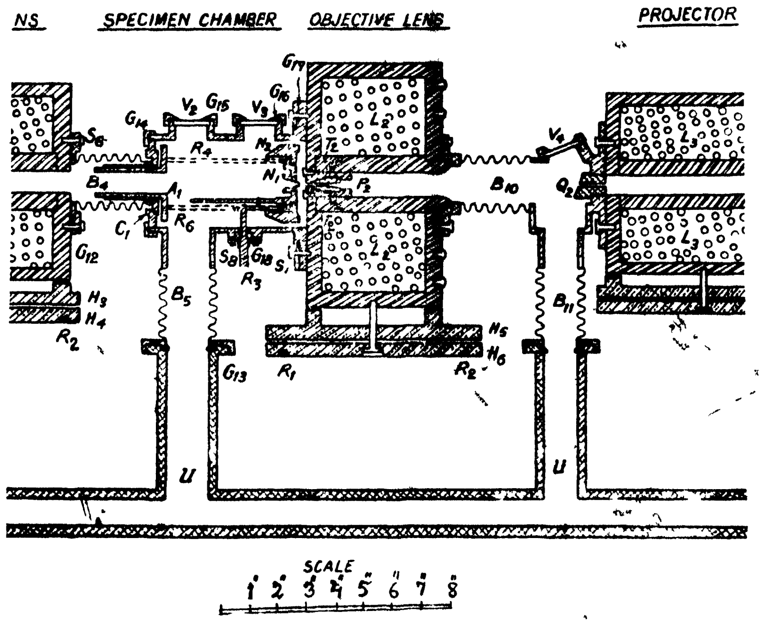


FIG. 4

Objective and Specimen Chamber of the New Microscope

$A_1$ brass end piece, $B_4$, $B_5$, $B_{10}$, $B_{11}$ sylphon connections, $C_1$ brass cylinder $G_{12}-G_{18}$ vacuum gaskets, $H_5$ $H_6$ brass carriage for movement of objective lens, $L_2$ objective lens coil, $N_1$, $N_2$ object stage with the movable part $N_1$ within the fixed part $N_2$, $P_2$ object lens pole piece, $Q_2$ intermediate viewing screen, $R_1$, $R_2$ rods permitting horizontal motion of objective lens $R_3$ sterio-motion rod, $R_4-R_6$ horizontal supporting rods for specimen stage, $S_6-S_8$ tightening screws, $T_2$ brass spacer in objective lens, $U$ vacuum manifold, $V_2$, $V_3$, $V_4$ viewing ports

horizontal rods $R_4 - R_7$, attached to the end piece $A_1$ which fits tightly into the brass cylinder $C_1$. For stereophotography the part $N_1$ of the object stage can be rotated through a small angle within the fixed part $N_2$. The tilting of the stage for stereography is accomplished by means of the rod $R_3$ which projects from the lower side of the chamber, through a Wilson seal. Two viewing ports $V_2$ and $V_3$ on the upper side of the chamber allow a view of the specimen stage through all operations.

A vertical section of the object chamber perpendicular to optic axis is shown in figure 5. Four hydraulic sylphon bellow $B_6 - B_9$ are

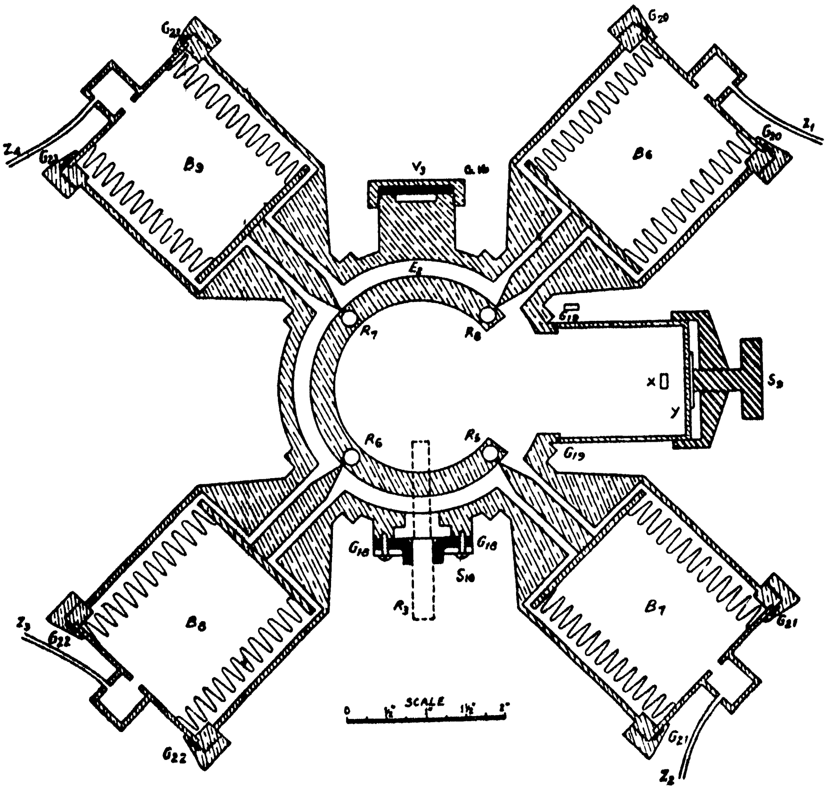


FIG. 5

Mechanism for Movement of Specimen Stage.

$B_6-B_9$ hydraulically operated sylphon bellows, $E_2$ brass ring holding the horizontal rods $R_4-R_8$ together, $G_{18}-G_{23}$ vacuum gaskets, $R_3$ sterio motion rod, $R_4-R_7$ horizontal brass supporting rods, $S_9$ tightening screw for air-lock chamber, $V_3$ viewing port, $X$ forked handle for removing specimen from stage to air-lock chamber and *vice versa*, $Y$ air-lock chamber, $Z_1-Z_4$ hydraulic connections from the sylphons to the control panel.

fitted at 90° to each other for moving the object stage in two perpendicular directions at right angles to the optic axis. In normal position the tips of the bellows rest in four accurately drilled holes in a brass ring $E_2$ fixed to the carrier rods $R_4$—$R_6$. The four bellows, slightly compressed, press against each other and help to keep the stage accurately centered and also at a fixed distance relative to the object lens pole piece $P_2$ (Fig. 4). By compressing and expanding the hydraulic sylphons it is possible to move the stage in a plane perpendicular to the microscope axis and thus explore different parts of the specimen. The fluid from the sylphons $B_6$ − $B_9$ passes through small copper tubes $Z_1$ − $Z_4$ to a corresponding unit on the control desk. It is thus possible to move the stage while looking at the image on the final fluorescent screen $Q_4$. The unit on the control desk is provided with both coarse and fine control adjustments, so that the specimen can be placed accurately in any desired position. The arrangement has no backlash and gives a very smooth motion of the specimen across the field of view.

The specimen change operation is performed with the help of the airlock arrangement shown in Fig. 6 which is a vertical section of the unit. When removing the specimen from the vacuum, a phosphor bronze fork $XX$ holds the bucket $W$ and a 90° rotation of the fork handle from outside releases the bucket from the specimen stage and brings it into the air-lock chamber $Y_1$. In this position the bucket is pressed from behind by the brass rod $R_8$ carrying the gasket $G_{27}$. Half a turn of the nut $C_1$, presses the gasket $G_{27}$ against the back of the bucket and seals it off from the microscope vacuum. While the bucket is held in this position, air is introduced into the airlock

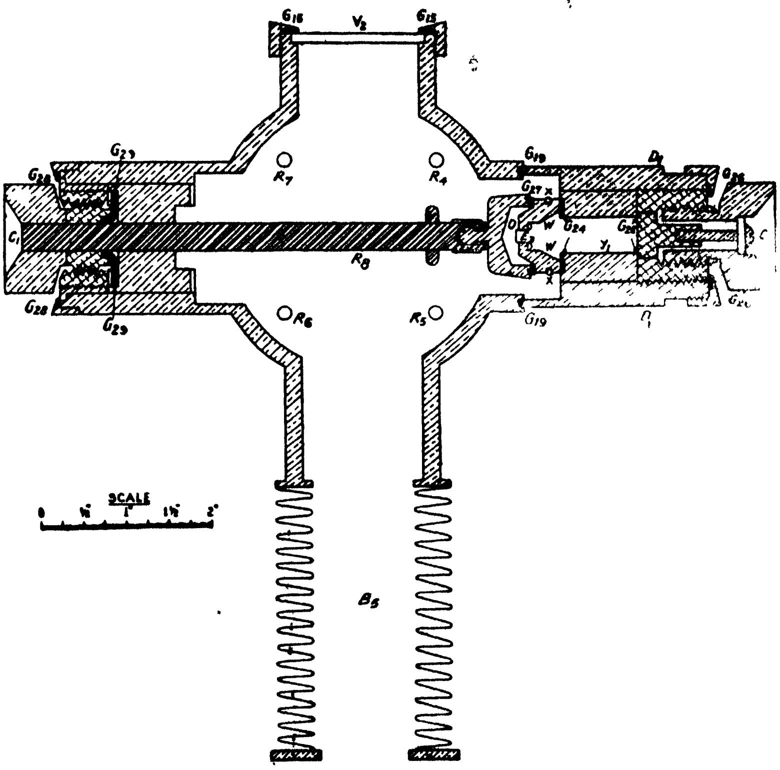

FIG. 6

Vertical Section of the Airlock Chamber at Right Angles to the Optic Axis.

$B_5$ sylphon connection to the manifold, $C_1$, $C_2$ split nuts for closing and opening the airlock chamber, $D_1$ brass box containing airlock arrangement, $E_3$ specimen holder, $G_{18}$, $G_{19}$, $G_{24}$, $G_{29}$ vacuum gaskets, $O$ object, $R_4-R_7$ four brass rods which support the stage and allow it to be moved by the hydraulic stage shifter, $R_8$ rod for sealing off (by means of gasket $G_{27}$) the specimen from the microscope vacuum, operating through the Wilson seal $G_{29}$, $V_2$ viewing window, $W$ section of the bucket which carries the specimen from the stage to airlock chamber $Y_1$ or vice versa, $Y_1$ airlock chamber.

chamber $Y_1$ by releasing the nut $C_2$. The specimen holder $E_3$ is now removed, through the opening made by removal of $C_2$.

The procedure is reversed for introduction of new specimens into the vacuum system. When a new specimen has been replaced with the bucket in the position shown in Fig 6, the nut $C_2$ is locked in first thereby isolating the airlock chamber $Y_1$ from the external atmosphere by means of gasket $G_{25}$. The rod $R_8$ is now pushed back and by means of the fork $XX$ the bucket is replaced in the specimen stage $X_1$. Once the bucket is held by the specimen stage, it is freed from the fork and can then be moved about by means of hydraulic arrangement described previously. Only the air trapped in the small chamber $Y_1$ is introduced into the microscope each time a specimen is replaced This arrangement permits quick replacement of specimens without seriously disturbing internal vacuum.

The whole airlock arrangement is contained in a brass box $D_1$ which is sealed to the specimen chamber by means of gasket $G_{19}$ and clamping screw $S_9$ (Fig. 5)

### *C. Objective Lens*

The objective lens $L_2$ is shown in Fig. 4. This coil is bigger than the condenser lens coil $L_1$, with an inner diameter 2 inches and outer diameter $7\frac{3}{4}$ inches. The whole coil is shrouded in an iron cylinder except for the brass spacer $T_2$. This lens contains a specially designed pole piece $P_2$ of very short focal length. As asymmetry of the pole piece finally limits the resolving power, great care was taken during construction so as to minimise asymmetries as far as possible. The objective lens forms an intermediate image on the intermediate viewing screen $Q_2$ attached to the projector lens.

### *D. Projector Lens*

The section of the projector lens $L_3$ together with the photographic unit is shown in Fig. 7. The projector lens coil is similar in construction to that of the condenser coil. The projector pole piece $P_3$ is inserted at the projector coil end remote from the gun. A copper rod with an axial hole and a coat of fluorescent material is fixed to the other end of the projector lens. This constitutes the intermediate fluorescent screen $Q_2$.

### *E. Photographic Unit*

Fig. 7 shows a vertical section of the photographic unit through the optic axis. The final image may be obtained either on the flourescent screen $Q_4$ or intercepted by the photographic plate $Q_3$. The plate magazine $K_2$ holds about twenty photographic plates and is demountable for loading in the dark room. The plates are moved forward by a pressure pad, the pressure being maintained by the vacuum. In order to release one plate into the photochamber the knob $R_9$ on the back of the photochamber is pulled. One plate then drops on to the carrier bar $R_{10}$, which can be moved from

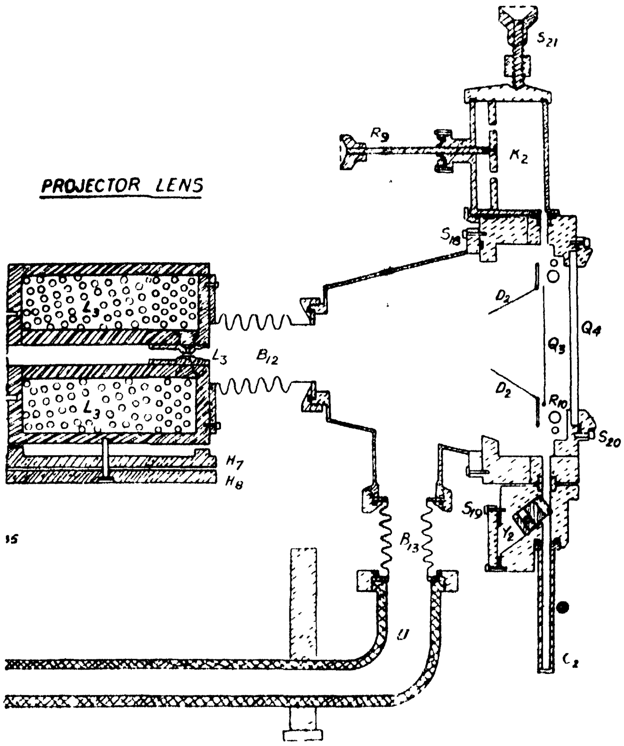


FIG. 7

Vertical Section of the Projector Lens and Photographic Chamber through Optic Axis $A_2$ terminal aluminium plate, $B_{12}$, $B_{13}$ sylphon connections to the rest of the microscope, $C_2$ plate receiver, $D_2$ adjustable photographic shutter, $F_4$ pressure pad holding the plates in readiness for dropping one at a time, $G_{37}-G_{50}$ vacuum gaskets, $K_2$ photographic plate magazine holding about twelve $3\frac{1}{4}'' \times 1''$ plates, $L_3$ projector lens coil, $R_7$ knob for releasing one plate at a time, $P_3$ projector lens pole piece, $Q_2$ intermediate flourescent screen, $Q_3$ photographic plate in position and carried by the carrier bar $R_{10}$, $Q_4$ final flourescent screen 6" diameter, $S_{16}$, $S_{18}-S_{21}$ gasket tightening screws, $U$ vacuum manifold connection, $Y_2$ valve interlock into the airlock chamber.

outside and the plate held in any position in the exposure field. Four exposures can be made on a single photographic plate. After the exposure is made the shutter $D_2$ is closed and the carrier bar lowered until the plate drops into the plate receiver box $C_2$. The air-lock valve $Y_2$ is now closed, air introduced into the receiver box and the plates removed for development. By means of a knob it is possible to swing the whole plate carrier and shutter mechanism out of the path of the electron beam so that the total area of the fluorescent screen (5 inches in diameter) can be utilised for visual observation of the micrograph.

The whole photographic unit is mounted on stainless steel guide rods by means of brass sleevings (Fig. 1, Plate XVIA). The unit is connected to the vacuum manifold and the projector lens by means of sylphon bellows $B_{12}$ and $B_{13}$.

## ELECTRONIC CONTROL CIRCUITS

### *A. High Voltage Supply for Electron Gun*

Figure 8, Plate XVIB is an illustration of the r.f. high voltage unit. The schematic diagram of the high voltage circuit is shown in Fig. 9.

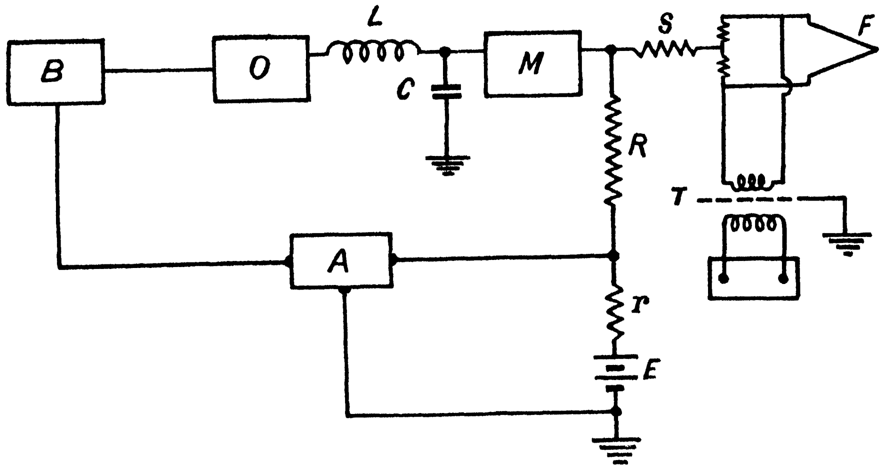


FIG. 9

Schematic diagram of high voltage generator and regulator

The circuit arrangement follows basically that developed by Hillier and Vance (1941). A high frequency oscillator $O$ supplies 500 volts at 50 kc/sec. to the series resonant circuit consisting of $L$ and $C$ of resonance frequency 50 kc/sec. The resonant circuit, by virtue of its inherent characteristic, steps up the input voltage $Q$ times across the terminals of the condenser $C$, $Q$ being the efficiency factor of the series resonant circuit. $Q$ in our case being about 40, the voltage across $C$ is 20 kv at 50 kc/s. This voltage is subsequently quadrupled and rectified by the unit $M$ in the manner first described by Greinacher (1921) and later used by Cockroft and Walton (1932). The unit $M$ incorporates a resistance-capacity network which serves to filter out the ripple content from the output voltage. The output, thus multiplied, rectified and smoothed, is 80 kV negative relative to the ground and is connected to the filament $F$ of the microscope through a current limiting resistance $S$.

The stability of this high voltage is an important consideration for best resolution of the electron microscope. In order that want of sharpness in the final image, due to fluctuations in the high voltage supply alone, will not exceed 10 Å, the maximum permissible variation in the high voltage supply

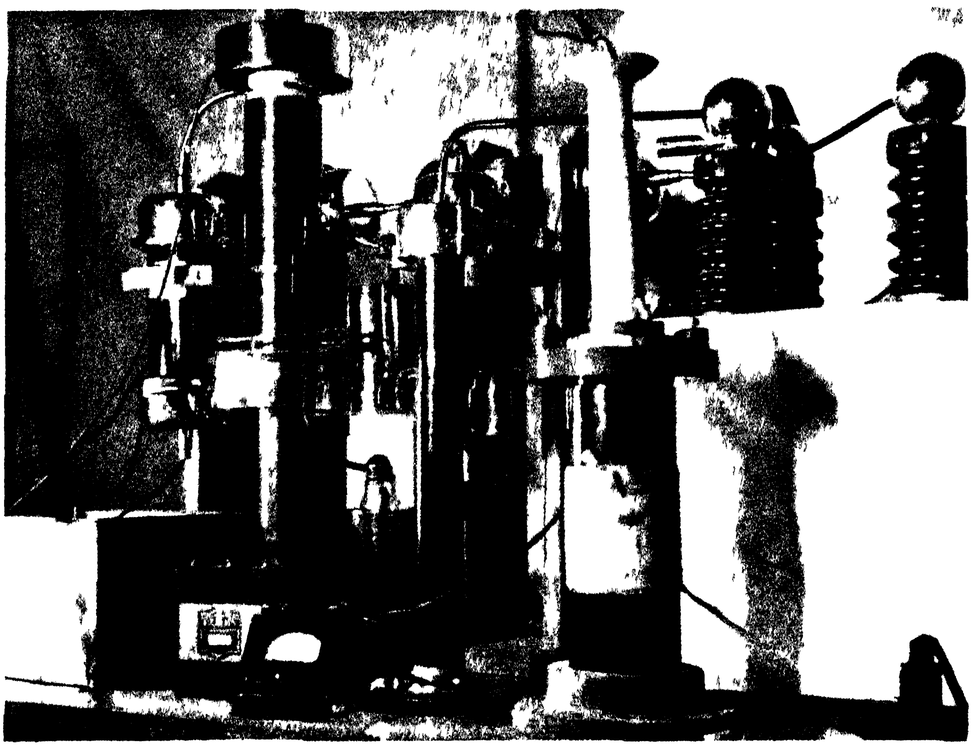

Fig 8

Photograph of High Frequency Voltage Unit is 1 part in 10, 000. This degree of stabilisation is achieved by making use of the principle of inverse feed back. By means of the voltage divider $R+r$ across the high tension generated at $M$, a part of the output voltage is balanced by the dry battery $E$ and the difference is applied to the direct current amplifier $A$. Any out of balance voltage due to instability is amplified by $A$ and then supplied to the electronic regulator $B$ which in turn controls the high tension anode input to the oscillator $O$. This feed-back amplifier arrangement is such that the variation in the oscillator output is in antiphase to those of the rectifier quadrupler unit and is capable of neutralising the original variation in high tension.

The d. c. amplifier $A$ consists of 2 stages, the output variation of which is in the same phase as that of input. This affects the electronic regulator $B$ which acts as a series load to the oscillator tube in $O$. The electronic regulator $B$ is similar to that used for regulating currents to various lenses (described below).

In addition to the above electronic voltage regulating system the whole a. c. supply is pre-stabilised by a constant voltage transformer of saturable reactor type.

*B Microscope Filment Supply*

The filament of an electron microscope usually requires 2-3 amperes at about 2 volts depending on the nature of the filament used. The filament supply has to be maintained at a very high negative voltage with respect to ground and also has to be accurately controllable for varying the intensity of the beam through the microscope. In the present unit, the microscope filament is heated by r. f. current of about 150 kc/s. This reduces the problem of electrostatic shielding and also simplifies that of high voltage insulation. The filament current is supplied by the secondary of a r. f. transformer $T$ through the primary of which passes the r. f. current from an oscillator. The anode voltage of the oscillator is supplied through a variable resistance by means of which the output of the oscillator can be easily regulated thereby controlling the microscope filament current.

The anode circuit of the oscillator is completed through a relay system, operated by the current from the ionisation gauge measuring the vacuum. Whenever the vacuum inside the microscope column falls below the limit, at which it is safe to operate the instrument, the ionisation gauge current becomes excessive and this automatically disconnects the anode voltage. The oscillation ceases at once and the filament of the microscope is thus saved from being burnt off.

*C. Current Regulators for Electromagnetic Lenses*

In a magnetic electron microscope it is essential to keep the currents through the various lens coils strictly constant. The stabilisation tolerences of the different current supplies for a resultant image unsharpness of 10 Å. can be computed theoretically (Zworykin, et al 1946) ; the values so obtained for an optimum aperture are as shown below :

| Supply | Tolerance $\Delta I/I$ |
|---|---|
| Condenser lens | $1.0 \times 10^{-3}$ |
| Objective lens | $5.5 \times 10^{-5}$ |
| Projector lens | $1.3 \times 10^{-4}$ |

The three lenses have three separate electronic regulators of the general type shown in figure 10.

A number of *6L6* beam tetrodes connected in parallel serve as the main power tubes driving the magnetising current through the lens coil *L* in series with a variable resistance *R* (eventually a number of resistors providing the coarse, medium and fine controls) The voltage drop produced by the load current on passing through the resistor *R* is compared to that of a dry battery and the difference is applied to the grid of a *6SJ7* tube. The anode voltage of this tube controls the grid excitation of the *6L6* tubes. The circuit is thus essentially a degenerative voltage regulator described by Hunt and Hickman (1939). It maintains a constant voltage across the control resistor *R* and with constant load, it acts as a good current regulator at very low frequencies. The regulator action is further helped by the screen connection of the *6SJ7* as shown in the Fig. 10. Variation in the current is obtained by variation of *R*.

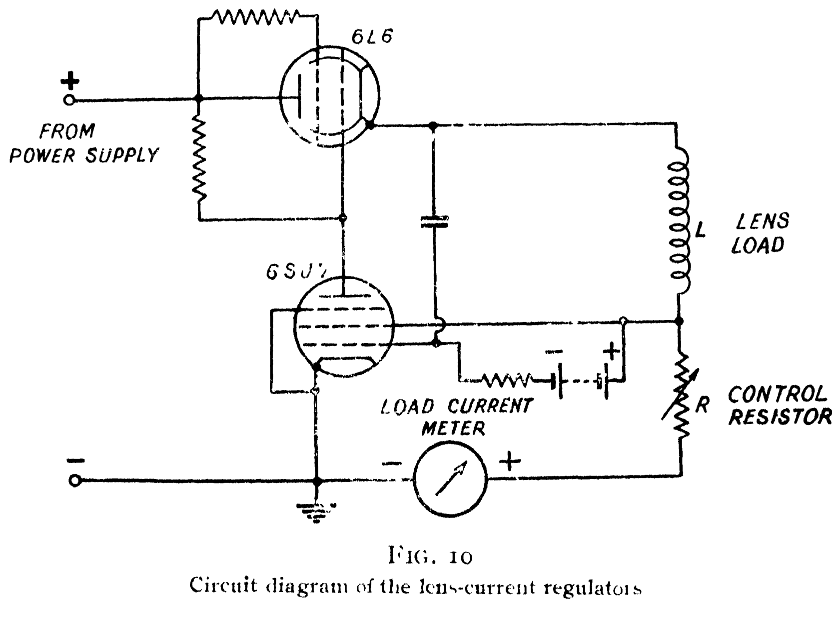


FIG. 10

Circuit diagram of the lens-current regulators

The simple electronic circuit alone is incapable of giving the required degree of stability. The primary a. c. supply is further pre-stabilised by a conventional constant voltage transformer of saturable reactor type.

With this circuit, it has been possible to secure the required order of stability. Slow drifts arising from changes in resistance due to heating or changes in thermionic emission, etc., have been observed, which have been minimised to some extent by using stabilised a. c. voltage to heat the filament of the tubes.

*D. Vacuum Gauge and Relay Circuits*

The electronic circuit also includes a thermocouple and an ionisation gauge for measurement of microscope vacuum. The thermocouple gauge is fitted before the diffusion pump and measures the rough vacuum produced by the mechanical pump. The ionisation gauge is placed after the diffusion pump very close to the microscope filament. It indicates the final vacuum produced at this point.

A relay is fitted in the ionisation gauge circuit which automatically shuts off the high voltage and the heating current of the microscope filament as soon as the pressure inside the microscope becomes more than $3 \times 10^{-4}$mm of mercury. Thus the vacuum gauge and the relay system protects the microscope from damage due to accidental failure of the high vacuum as a result of a suddenly developed leak. A second relay is incorporated in the high voltage circuit, which shuts off the high voltage, if for any reason, the current drawn from the high voltage becomes excessive. This relay therefore protects the components of high voltage circuit in case of an accidental failure of electric insulation.

## CONCLUSION

In this preliminary report the constructional details of the new electron microscope have been given.

It will be seen from the introduction, that in every country the electron microscopes were first developed in the university laboratories. It was only after a great deal of experience had been gained, during researches carried out in these laboratories, that it was possible to produce an electron microscope commercially, first in Germany nearly ten years ago and then in U. S. A., and only last year in countries like England, Holland and France. This paper contains an account of the attempt to construct for the first time in a university laboratory in this country an instrument of this type.

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In this project we have been helped by one of the pioneers in this field, *viz.*, Prof L. Marton. We are all indebted to him for his advice and guidance in designing the instrument and help in the procurement of parts from U. S. A. Mr. Bert F. Bubb of Stanford University has been of great assistance in the mechanical construction as well as in designing. Apart from the mechanical parts, the complete electronic power system consisting of the high frequency oscillators, both for the microscope filament heating as well as for the rectified 80,000 volt d.c. source for the electron gun, the highly stabilised current supplies for the three electromagnetic lenses, the vacuum gauge and the safety relay systems were built up in our laboratory. Some of the local radio manufacturers particularly Messrs. Indian Radio Institute and India Radio Manufacturing Co. of Calcutta, have helped us by making high $Q$ radio frequency coils and transformers according to our requirements.

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